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Nanotechnology Propellant Health Monitoring Sensors; Success Though Multi-Stakeholder Interest



Kenneth Watkins and Austin McKinney—Polymer Aging Concepts, Inc.

NanoTechnology for Defense Conference (NT4D)
17-20 November 2014

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Polymer Aging Concepts, Inc.,

AgeAlert
Real-Time Product Age Tracking

®

Outline

- Introduction/PHM Challenge
- How AgeAlert PHM Sensor/Tags Work
- Stakeholder Contributions
- Where We Go From Here!

Introduction: Polymer Aging Concepts, Inc.

- Incorporated 2003, Georgia
- Lab/office in Dahlonega, GA
- 7 Employees
- Recipient of \$4M in Dept. of Energy and Dept. of Defense R&D funding
- Commercial Development Project (O&G Equipment Mfg.)

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Partners in Development



Missile Defense Agency

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Introduction: “The Propellant Health Monitoring (PHM) Challenge”



“Development of innovative systems to allow real-time health monitoring of solid rocket motors assessing both the current and future state.---AFRL SBIR solicitation

“Access viable approaches to cost effective, reliable service life extension testing of ordnance devices.” ---MDA SBIR Solicitation

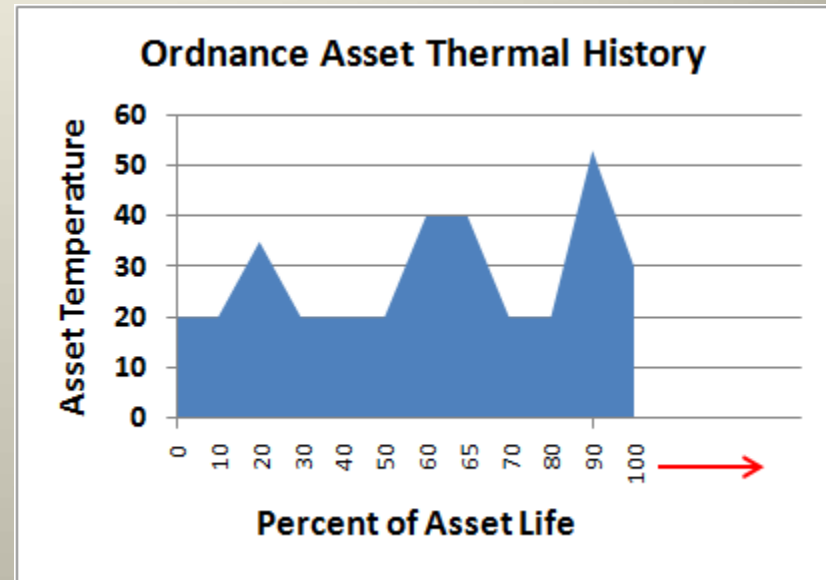
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Propellant Health Monitoring (PHM): Thermal Aging Challenges

Mechanical, chemical, and physical properties of composite and NC base propellants degrade due to thermal and other environmental conditions.

Problem: Tracking these aging properties is often destructive, expensive and complex.



Ordnance thermal history may be varied and unpredictable, complicating testing schedules and life extension programs.

Propellant Thermal Aging

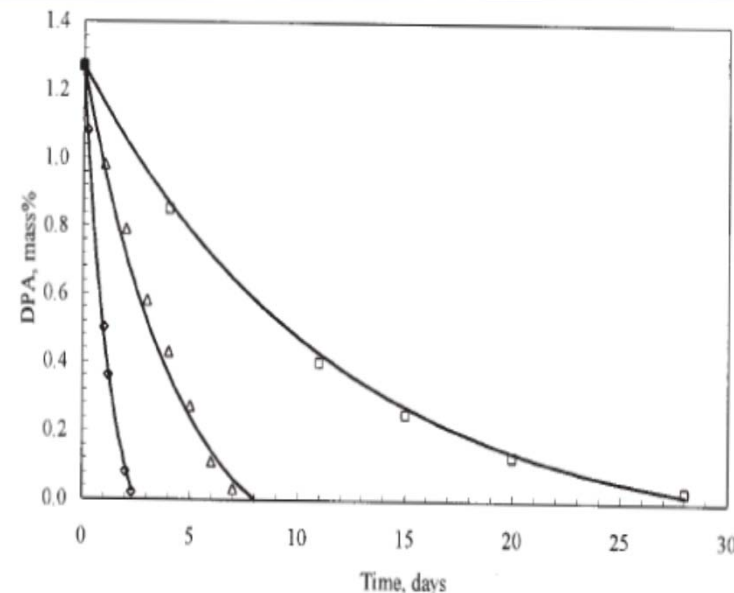
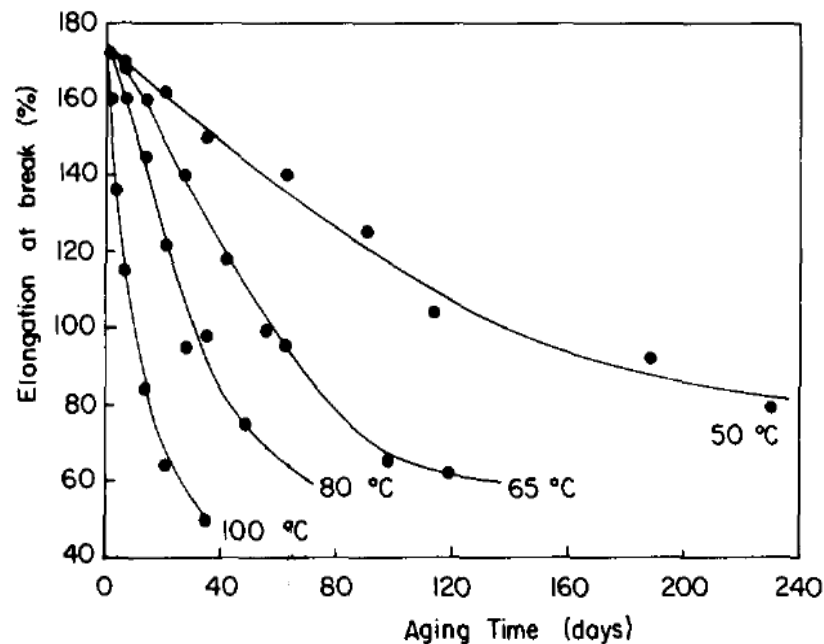
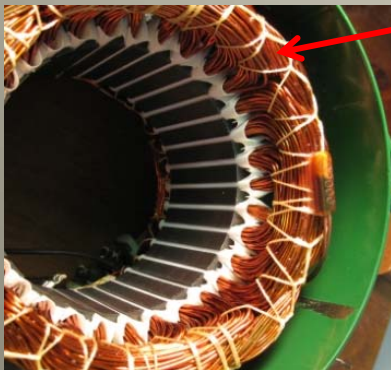


Fig. 1. Diphenylamine consumption in the single base gun propellant NC-27 – Description by a reaction of shifting order. □ – 80 °C; Δ – 90 °C; ◇ – 100 °C.

Destructive testing is used to determine critical degradation parameters such as propellant elongation properties (Akbas et al., left graph) for composite propellants and stabilizer depletion (Jelisavac, right graph) for NC based propellants. (Literature examples)

Enter AgeAlert® Conductive Composite Condition Monitoring Sensors

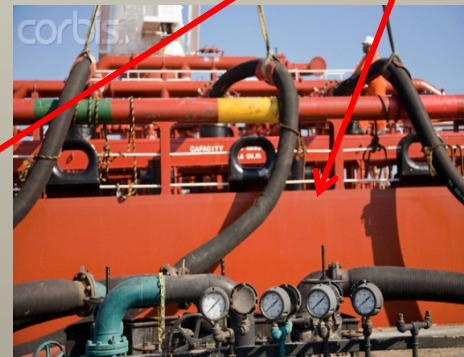
A new non-destructive, platform technology which will tell users in *real-time* when components made of polymers have degraded to design limits



**Electric Motor
Insulation**



**Wire & Cable
Insulation**



Rubber hoses

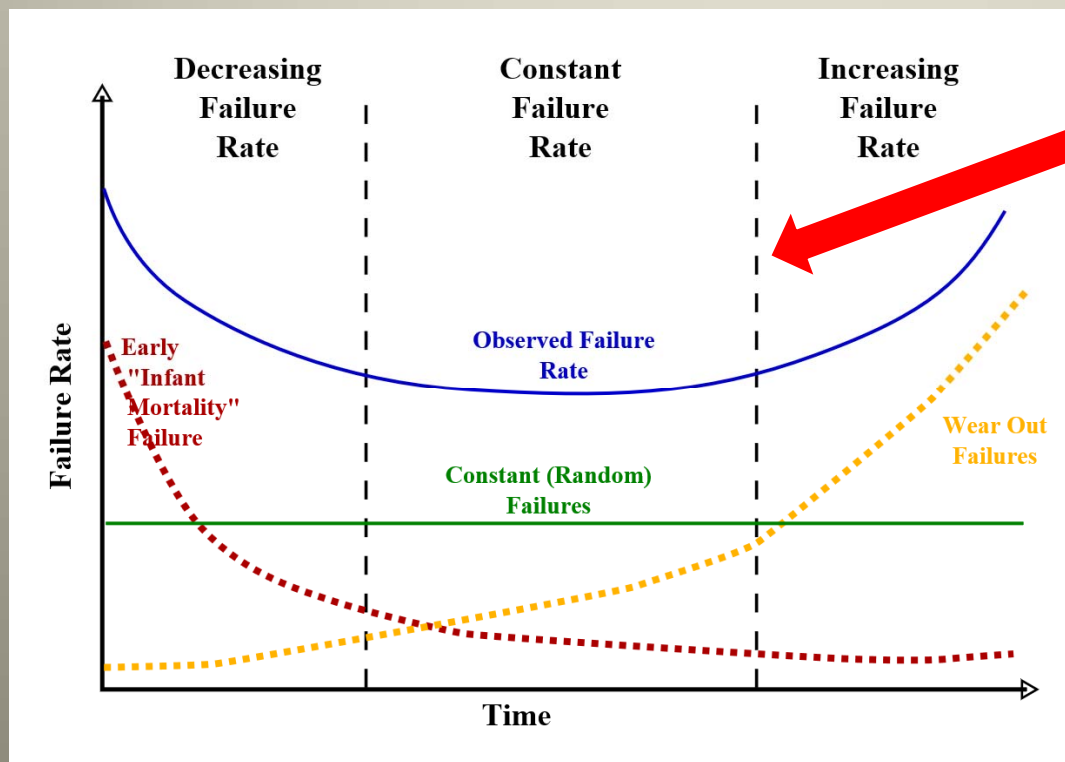


Propellants

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What Are “Design Limits?”

Mechanical, physical, or chemical condition of the propellant which indicates “living on borrowed time”.

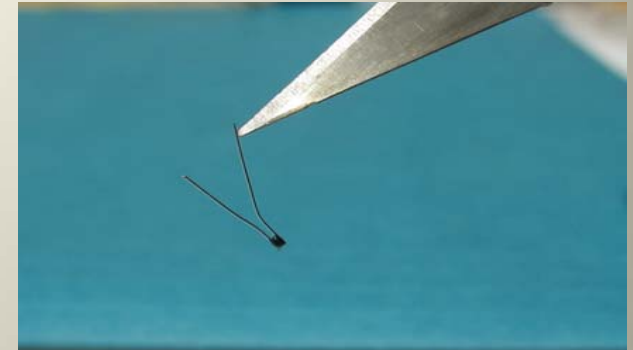


- This line (increasing failure rate) Moves with environmental changes!

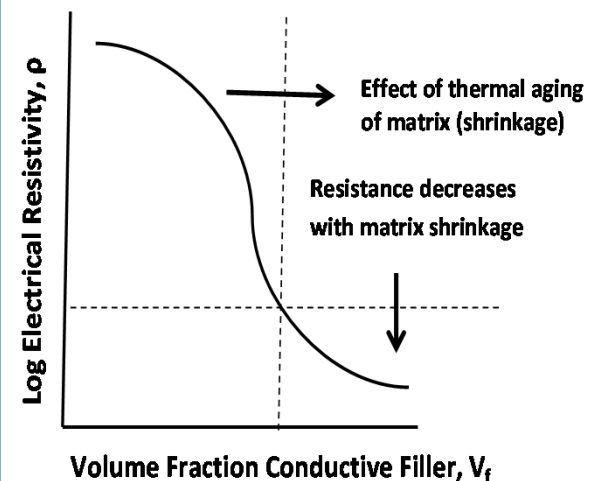
- Simple “shelf life” (time) is inaccurate in complex thermal environments!

How Does AgeAlert[®] Work?

- Sensor is conductive composite “surrogate” of the propellant having a matrix of non-energetic propellant components and a conductive filler
- Sensor is placed in similar thermal environment as propellant; no embedment required
- Sensor resistance decreases as sensor matrix (propellant component) shrinks with time under thermal environments.

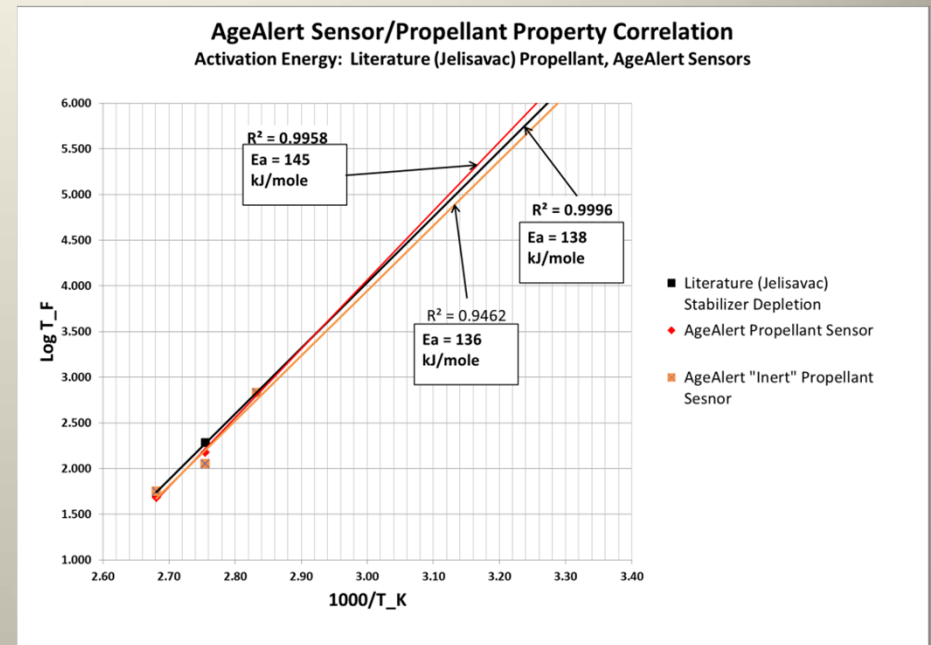


Electrical Percolation of Conductive Composite



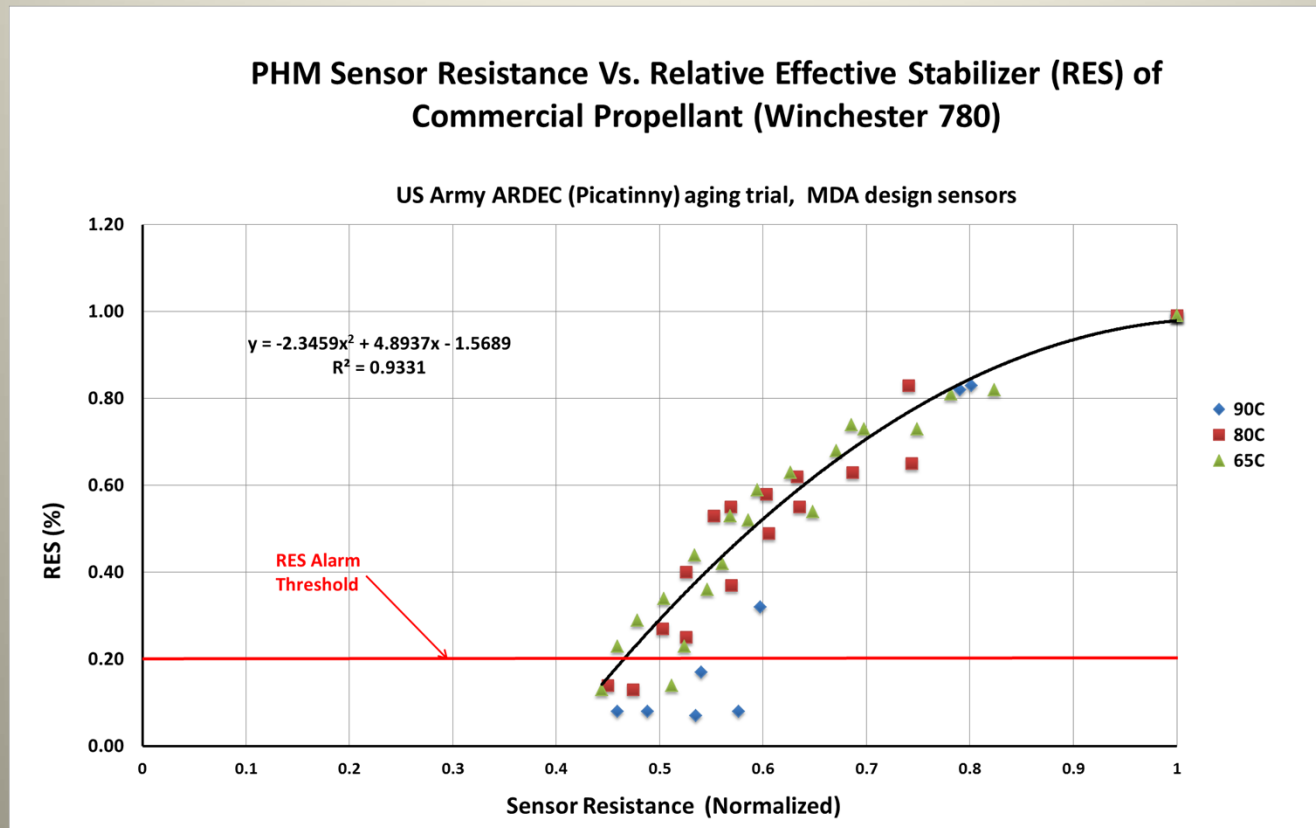
How Does AgeAlert[®] Work?

Since AgeAlert sensor resistance and propellant properties are both affected by similar thermally-induced chemical reactions, the resistance of AgeAlert sensors placed in same thermal environment as monitored propellant correlates to selected propellant properties that represent design end-of-life.



AgeAlert sensor resistance during thermal aging of commercial propellant provides very similar Arrhenius behavior to destructive propellant stabilizer depletion measurements

Commercial NC-Based Propellant Health Monitoring with AgeAlert Sensors



Direct (temperature independent) correlation of sensor resistance to chemical property (remaining stabilizer level)

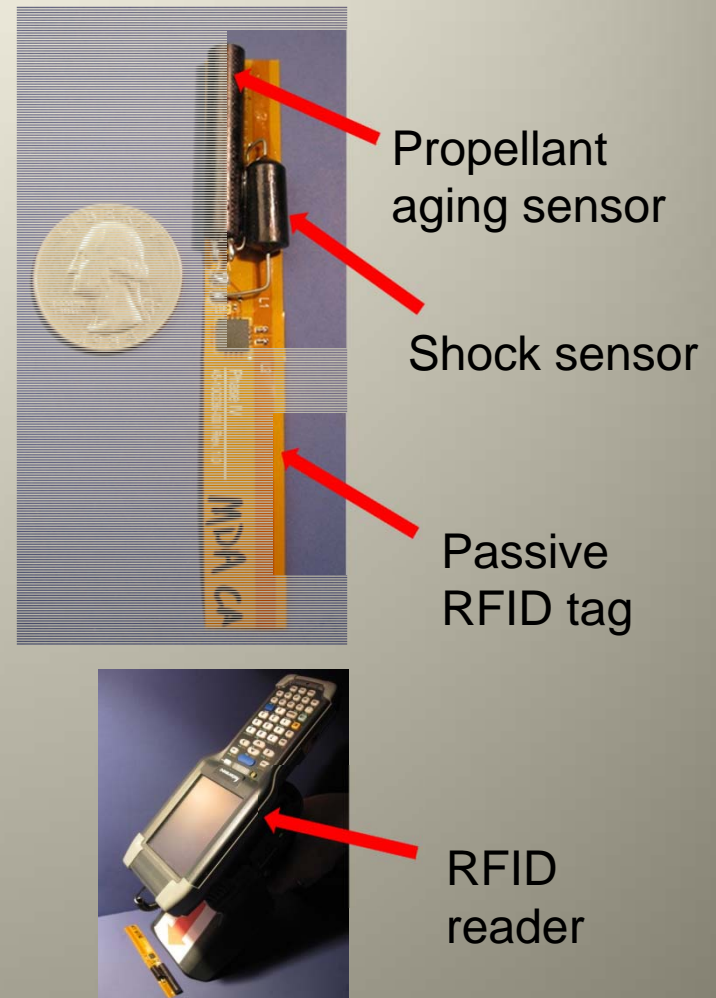
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Integration of AgeAlert Sensors and Passive RFID

Passive AgeAlert sensors integrate well with *passive* (no battery!) RFID technology:

- RFID reader provides rf energy to read tag providing tag identification and sensor resistance.
- Reader accesses algorithm to convert sensor resistance to remaining propellant life
- Passive shock (threshold) can be added
- Reader access to secure server means real time updates



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Smart Shelf Life Application for Propellants: “PHM System on a Tag”

- Wired or wireless ordnance identification **AND** propellant condition
- **Maintenance-free and life of asset!**
- Low life cycle cost
- Easily attached to ordnance asset, tube or packaging, no embedment required
- Easily interrogated throughout life cycle without special training or complex equipment
- “Stand alone” or Integrated with current and proposed IVHM systems



CONNECTED

ID	°C	Ohms	%Life	Mech
E036115E	21.14516	7265.625	25	GOOD

Remaining Design Propellant Life

Reader Options

Stakeholder Inputs During Development (Customer/Prime Contractor/Propellant Contractor)

- Compatibility with existing hardware/software -“Don’t make me bolt or wire it in a motor!” (recertification)
- Need for field testing of prototype SSL PHM tags (Prime Contractor/Propellant Contractors)
- Variable Temperature Testing (AFRL/Prime Contractor)
- Extreme Temperature Cycling (Prime Contractor)
- Address known issues (All)
 - Sensor stability and variation
 - Wired SSL versions (HERO)
 - Temperature/humidity/shock sensitivity
 - Read range
 - Smaller/lighter
 - Manufacturability/cost
- Commercialize!!!!



AgeAlert SSL Tag “Stakeholders”

Entity	Involvement/Instrument	Objective
AFRL	Funding (Composite Propellant Sensors)/SBIR	Development of PHM sensor/tags for composite propellants
MDA	Funding (NC Propellant Sensors)/SBIR	Development of PHM sensor/tags for NC propellants
Aerojet Rocketdyne	Consultant/Propellant Aging Contractor for AFRL/MDA	Development and testing of PHM sensor/tags for composite and NC propellants
ATK	Consultant/Propellant Aging Contractor for MDA project	Target composite propellant aging and correlation
Prime Contractor	SSL Tag testing (interest)	Possible commercialization
US Army (ARDEC, Picatinny)	Testing of NC PHM sensors, tags/CRADA	Possible PHM tag use for bulk propellant monitoring
US Army (MRDEC, Huntsville)	Testing of NC PHM tags/(Discussions)	Lab and field testing of NC PHM tags for NC propelled rockets
US Navy (NAVAIR, China Lake)	Testing of composite and NC SSL Tags/(Discussions)	Monitoring shelf life of stored rocket motors

Proposed Long Term Missile Storage Trial

NAVAIR/China Lake

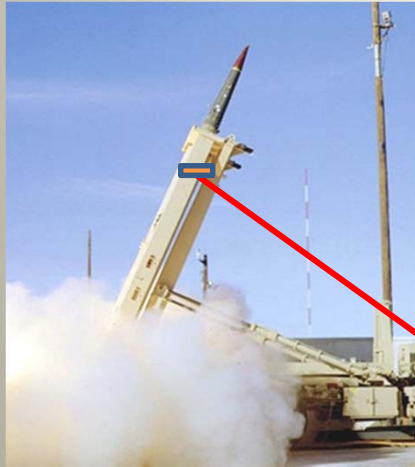
- Tracking new assets (relatively straightforward):
 - Attach SSL tags to new assets/containers/packaging from time they leave manufacturer.
- Track “aged” assets (tougher!):
 - Determine current aged condition:
 - NDT
 - DT of similar stored assets
 - “Extrapolation” of stored assets based on actual aging and time in service
 - Reset remaining life for each asset (reader or secure server) based on current aged condition
 - Screen remaining life with tags (reduced DT)



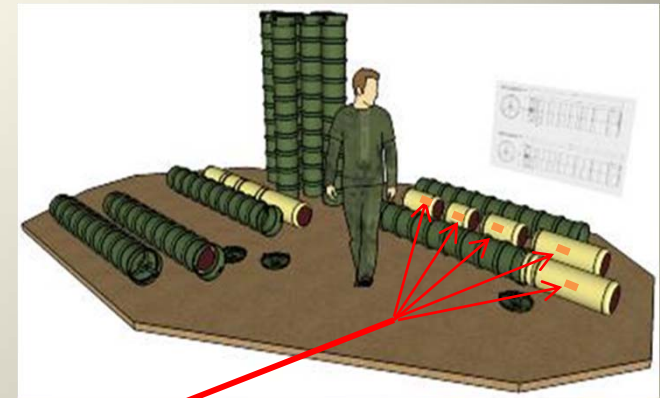
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Polymer Aging Concepts, Inc.,

AgeAlert® Smart Shelf Life (SSL)Tag for Propellant Health Monitoring (PHM)



Polymer Aging Concepts, Inc.
info@AgeAlert.com



- **First** wireless age-monitoring tag incorporating inert propellant components for accurate thermal age tracking of composite and NC-based propellants
- “PHM system on a tag”
- Passive, “inherently integrating” sensor reduces cost and complexity of propellant monitoring
- “Life of Asset”, maintenance free (no batteries)
- Simple non-destructive screening identifies prematurely aged ordnance for repair/replacement
- Provides objective data in support of reliability improvement and service life extension programs
- Prototypes available for testing!



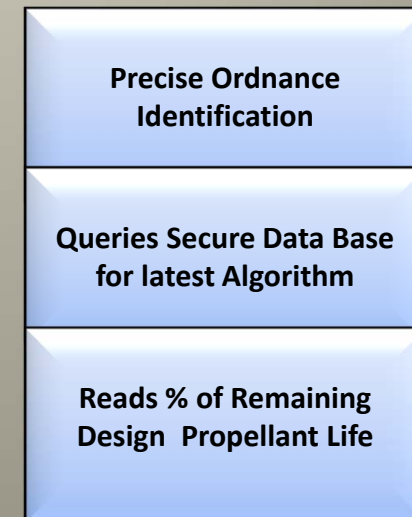
SSL Propellant Sensor/Tag



SSL Reader

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Field Use/Lab Data



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